

Climate Change Trends and Vulnerabilities, Lava Beds National Monument, California

Patrick Gonzalez (U.S. National Park Service; University of California, Berkeley)

Whitney B. Reiner (University of California, Berkeley)

Natural Resource Stewardship and Science, U.S. National Park Service, Berkeley, California
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Climate Trends for the Area within Park Boundaries

- **Historical temperature** Average annual temperature in the park increased at the statistically significant rate of $+1.2 \pm 0.5^{\circ}\text{C}$ ($2.2 \pm 0.9^{\circ}\text{F.}$) per century in the period 1950-2010 (Table 1, Figure 1). Of the four seasons, summer temperature experienced the greatest rate of increase at $+2 \pm 0.9^{\circ}\text{C}$ ($3.6 \pm 1.6^{\circ}\text{F.}$) per century.
- **Historical Precipitation** Total annual precipitation decreased in the period 1950-2010, but the rate was not statistically significant (Table 1, Figure 2).
- **Spatial patterns** Historical temperature increases have been greater in the south-central part of the park (Figure 3). Historical precipitation decreases generally increased from west to east across the park (Figure 4).
- **Future projections** If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project substantial warming and changes in precipitation (Table 1, Figure 5).
- **Projected precipitation** For projected total annual precipitation, the average of the ensemble of climate models projects an increase, but approximately one-quarter of the individual models project decreases.
- **Aridity** Climate water deficit, the difference between precipitation and actual evapotranspiration, decreased across the area between the periods 1900-1939 and 1970-2009, indicating that conditions became less arid (Rapacciuolo et al. 2014). In the future, even if precipitation increases, temperature increases may overcome any cooling effects, leading to increased climate water deficit and decreased soil moisture. Modeling of climate water deficit under high emissions projects more arid conditions in the region of the park by 2100 AD (Thorne et al. 2015).
- **California drought historical** A severe drought struck California from 2012 to 2014, with the lowest 12-month precipitation total combining with the hottest annual average temperature

(Diffenbaugh et al. 2015). Analyses of the Palmer Drought Severity Index (PDSI), an indicator of near-surface soil moisture, for the period 1901-2014 indicate that 2014 was one of the ten driest years for the region of the park (Williams et al. 2015). Analyses of PDSI for the period 1896-2014 showed that, while the probability of low precipitation years has not increased, the hotter temperatures caused by human-caused climate change have increased the probabilities of drought through increased probabilities of high temperature and low precipitation co-occurring in a single year (Diffenbaugh et al. 2015). For the State of California as a whole, human-caused climate change accounted for one-tenth to one-fifth of the 2012-2014 drought (Williams et al. 2015).

- **California drought projection** Hotter temperatures caused by human-caused climate change have increased the probabilities of drought through increased probabilities of high temperature and low precipitation co-occurring in a single year (Diffenbaugh et al. 2015). Under the highest emissions scenario, additional warming may increase the probability that, by 2030, any annual dry period co-occurs with drought-level heat (Diffenbaugh et al. 2015).
- **Extreme heat** Projections under the highest emissions scenario project an increase of up to five more days per year with a maximum temperature $>35^{\circ}\text{C}$ (95°F.) (Kunkel et al. 2013).
- **Extreme storms** Projections under the highest emissions scenario project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5-6 years (Walsh et al. 2014). Information on seasonality is not currently available.

Historical Impacts in the Region Attributed to Human-Caused Climate Change

- **Wildfire** Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor determining how much land burned, even during periods of active fire suppression (Littell et al. 2009).
- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including counts in California, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km per year from 1975 to 2004, attributable to human-caused climate change (La Sorte and Thompson 2007). Further analyses demonstrate poleward shifts in winter distributions of six raptor species listed by the NPS Inventory and Monitoring Program as breeding in the park (American Kestrel (*Falco sparverius*), Golden Eagle (*Aquila chrysaetos*), Northern Harrier (*Circus cyaneus*), Prairie Falcon (*Falco mexicanus*), and Red-tailed Hawk (*Buteo jamaicensis*)) or observed in the park (Rough-

legged Hawk (*Buteo lagopus*)) (Paprocki et al. 2014).

Future Vulnerabilities in the Region

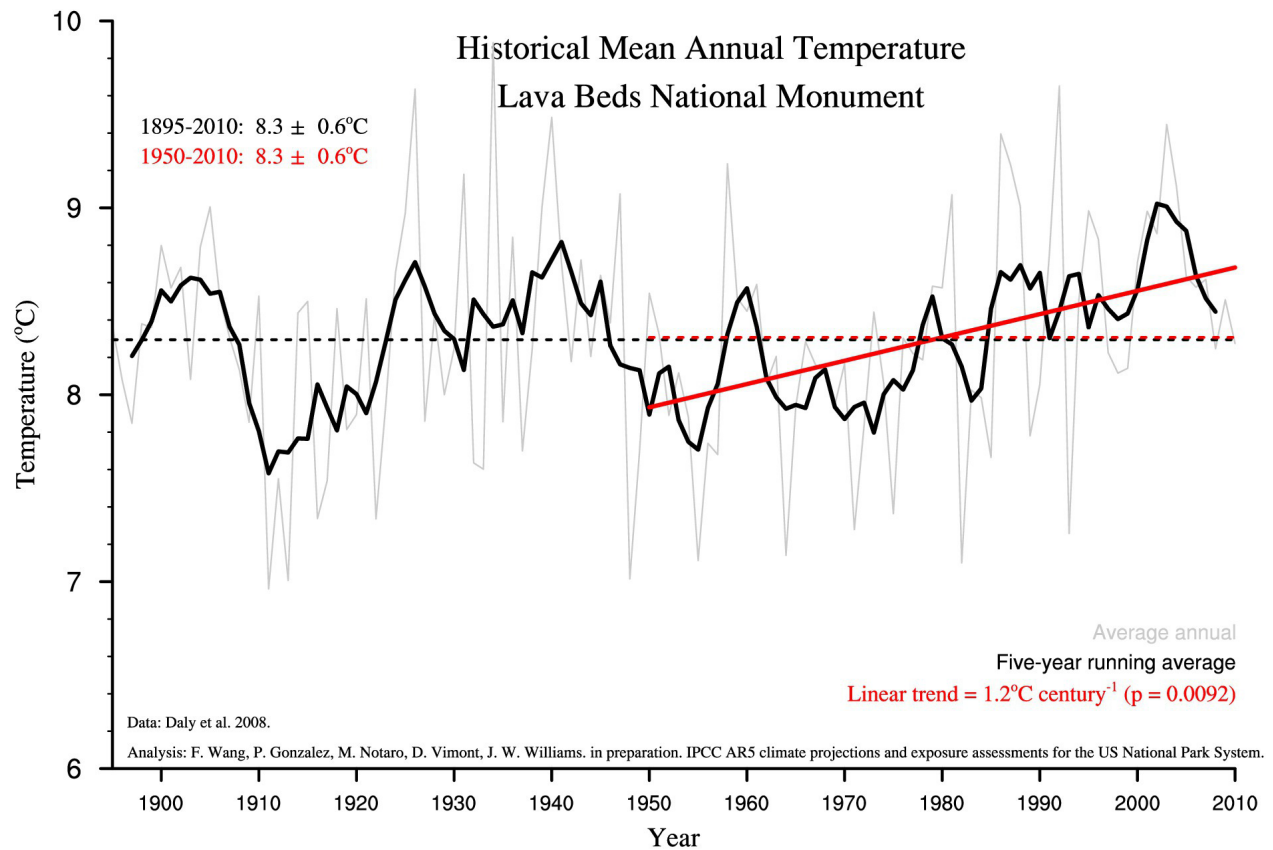
- **Wildfire and invasive species** Under high emissions, fire frequencies could increase by one-third to one-half by 2050 (Mann et al. 2016) and the region of the park would continue to provide suitable habitat for invasive cheatgrass (*Bromus tectorum*) and, although not yet detected in the park, yellow starthistle (*Centaurea solstitialis*) (Bradley et al. 2009). At three sites in the park (Gillems Camp, Fleener Chimneys, Merrill Cave) invasive cheatgrass germination decreased for one year following prescribed fires in the spring, but not after prescribed fires in autumn, while native dicot germination increased substantially after prescribed fires in the spring and less after prescribed fires in autumn (Ellsworth and Kauffman 2013). Native bunchgrasses showed high recovery and flowering after spring and autumn prescribed burns (Ellsworth and Kauffman 2010). Analysis of fires in the Great Basin, including the region of the park, indicated that, from 1980 to 2009, 13% of the surface area of invasive cheatgrass-dominated lands burned, double the fraction of other vegetation types, and that cheatgrass fires tended to increase after wet years (Balch et al. 2013). The projections of greater temperature increases in autumn than in spring and potential precipitation decreases in autumn and increases in spring suggest fire increases in the autumn, possibly leading to increased cheatgrass.
- **Cave ice** Monitoring since 1990 of ice in eight caves in the park found decreasing ice in seven of them and total loss of perennial ice in three of them (Merrill Cave, M-470, M-475) (Kern and Thomas 2014). Merrill Cave has contained ice deposits since the Pleistocene (10 000 years ago), but an ice deposit in the lower part of the cave has melted since 1997 (Fuhrmann 2007). Comparison of ice levels with temperature and precipitation measured at park headquarters shows that winter temperature and precipitation have not shown consistent trends, but that summer temperature has risen consistently, suggesting that hotter summer air and infiltration of warmer summer water may be causing the ice loss (Kern and Thomas 2014). Disturbance by visitors, a seismic event, decreased water due to uptake by increased western juniper (*Juniperus occidentalis*) above the cave also may contribute to ice loss (Fuhrmann 2007).
- **Pika** Although the American pika (*Ochotona princeps*) has been extirpated from some sites on the Modoc Plateau east of the park and other sites west of the park, the pika is still present in Lava Beds National Monument (Beever et al. in press). Their distribution is correlated more

to vegetation than to climate, although vegetation composition is related to microclimate (Ray et al. 2016). Research in other protected areas in the western U.S. found that exposure to relatively high temperatures may limit dispersal in the pika (Castillo et al. 2016). Pikas are vulnerable to losing habitat as warm temperatures shift upslope (Beever et al. 2011). Records of the occurrence of the pika in the Great Basin from 1898 to 2008 reveal a mean upslope shift of 360 m elevation and extirpation at 10 out of 25 research sites (Beever et al. 2011). Climate-based species distribution models do not accurately represent pika distributions in the park, so no local projections of the pika under climate change are currently available (Schwalm et al. 2016).

- **Bald eagle** Analyses of bald eagle (*Haliaeetus leucocephalus*) winter roost habitat in the Caldwell Butte area in the southern part of the park found that uneven-aged stands with ponderosa pines that are large (diameter at breast height > 80 cm) and old (age > 200 years) provided primary habitat (Stohlgren and Farmer 1994). This suggests that any potential reduction of old-growth conifers under climate change could increase the vulnerability of the eagle.
- **Bats (aridity)** Increasing aridity can reduce bat reproduction (Adams and Hayes 2008). Bats may be disproportionately affected by increased aridity relative to other mammals because small body size and a large surface area-to-volume ratio predisposes them to dehydration through evaporative loss (Adams 2010).
- **Bats (White nose syndrome)** White-nose syndrome is a disease caused by the invasive fungus *Pseudogymnoascus destructans*, which has infected and killed big brown bats (*Eptesicus fuscus*) and little brown bats (*Myotis lucifugus*) in parts of the U.S., but white-nose syndrome is currently not present in the park. White-nose syndrome is associated with precipitation frequency (30% of days with any precipitation), annual temperature (38-40°C), mean temperature of the wettest quarter (2-17°C), and precipitation during the wettest month (<100 mm) (Flory et al. 2012). Under historical and projected climate, some conditions are suitable in the park for white-nose syndrome, so climate change could contribute to its future occurrence, although the speed and severity of the historic spread of white nose syndrome suggest that factors other than climate dominate.

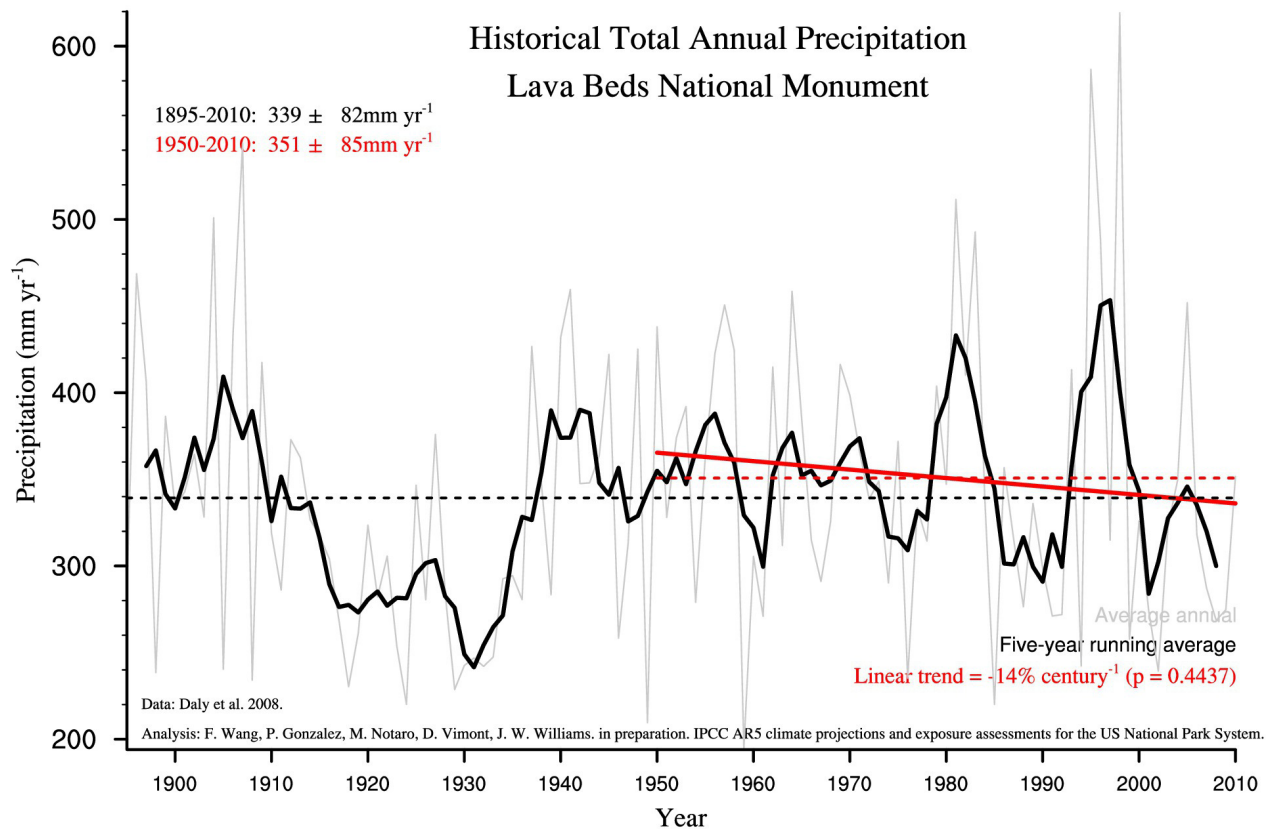
Table 1. Historical rates of change and projected future changes per century in annual average temperature and annual total precipitation for the park as a whole (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). The table gives the historical rate of change per century calculated from data for the period 1950-2010. The U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. The table gives central values with standard errors (historical) and standard deviations (projected).

	1950-2010	2000-2100
Historical (1950-2010)		
temperature	+1.2 ± 0.5°C per century (2.2 ± 0.9°F. per century)	
precipitation	-14 ± 18% per century	
Projected (2071-2100 compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature	+1.7 ± 0.6°C per century (+3.1 ± 1.1°F.)	
precipitation	+5 ± 8% per century	
Low emissions (IPCC RCP4.5)		
temperature	+2.7 ± 0.7°C per century (+4.9 ± 1.3°F.)	
precipitation	+4 ± 9% per century	
High emissions (IPCC RCP6.0)		
temperature	+3 ± 0.8°C per century (+5.4 ± 1.4°F.)	
precipitation	+6 ± 11% per century	
Highest emissions (IPCC RCP8.5)		
temperature	+4.7 ± 0.9°C per century (+8.5 ± 1.6°F.)	
precipitation	+7 ± 13% per century	

Figure 1.

Main conclusion: Temperature increased at a statistically significant rate in the park.

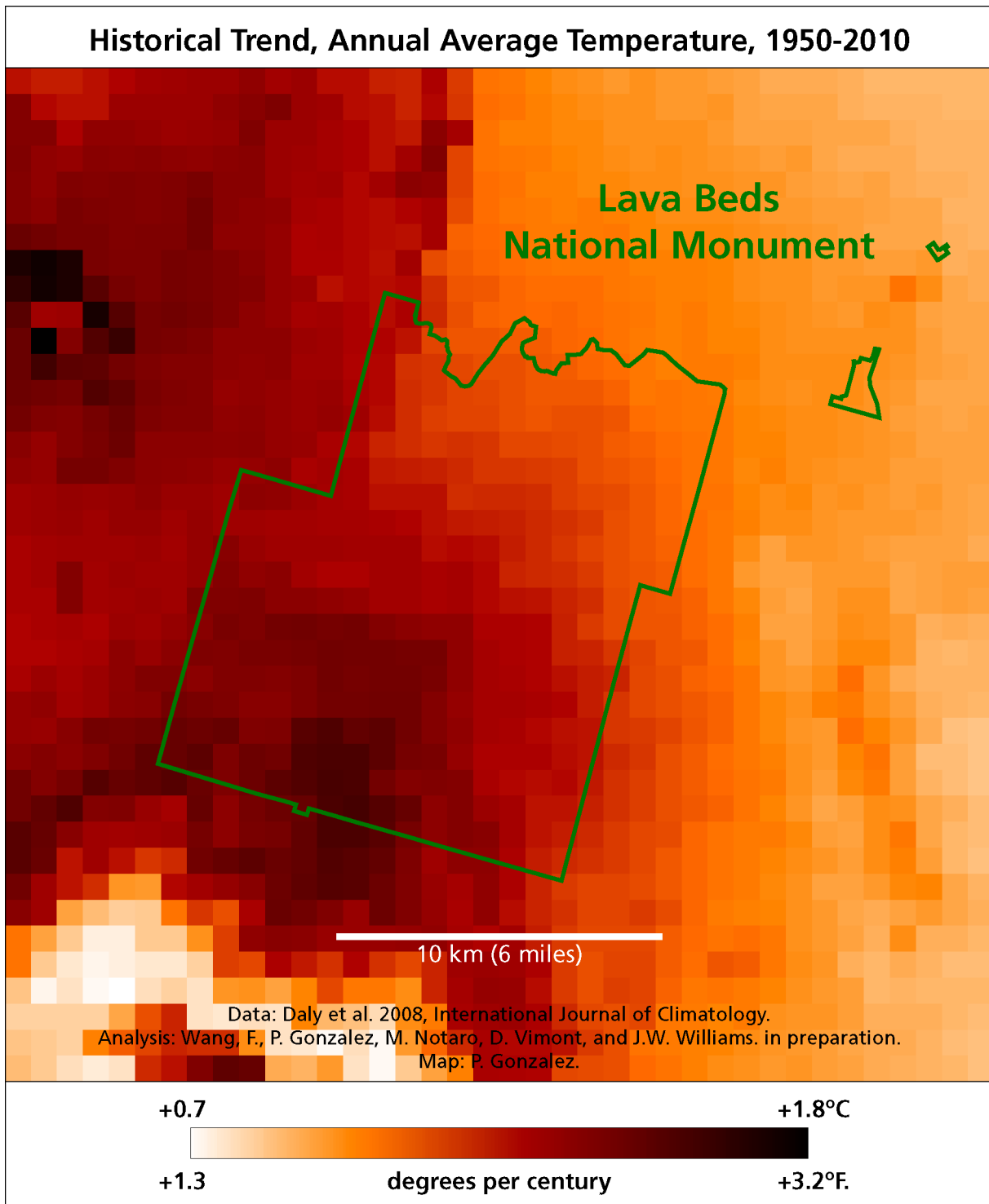
Because many stations in the U.S. weather station network established before 1950 have been discontinued, the period starting 1950 provides a more consistent time series. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 2.

Main conclusion: Precipitation decreased in the park, but the rate was not statistically significant.

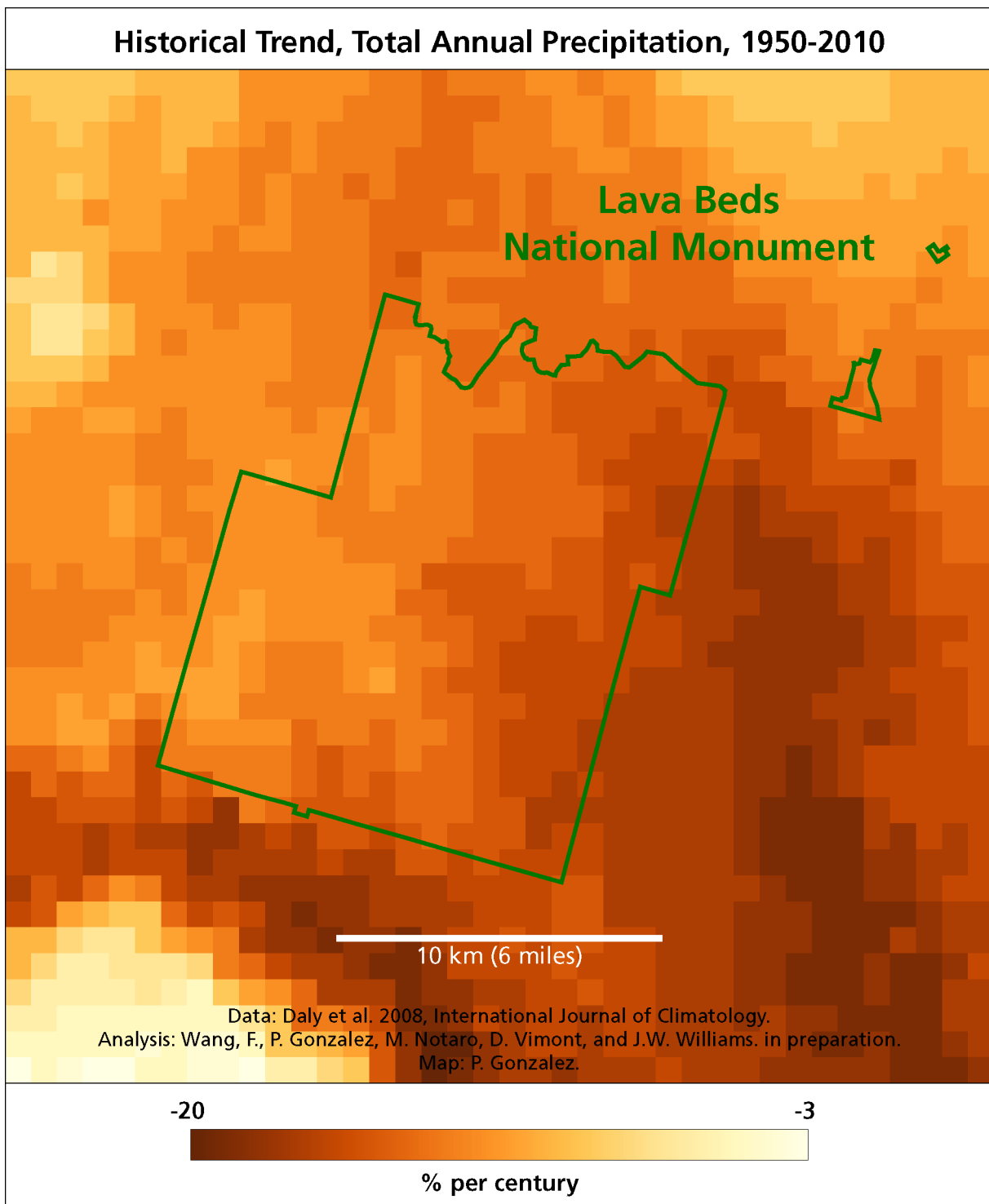
Because many stations in the U.S. weather station network established before 1950 have been discontinued, the period starting 1950 provides a more consistent time series. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 3.



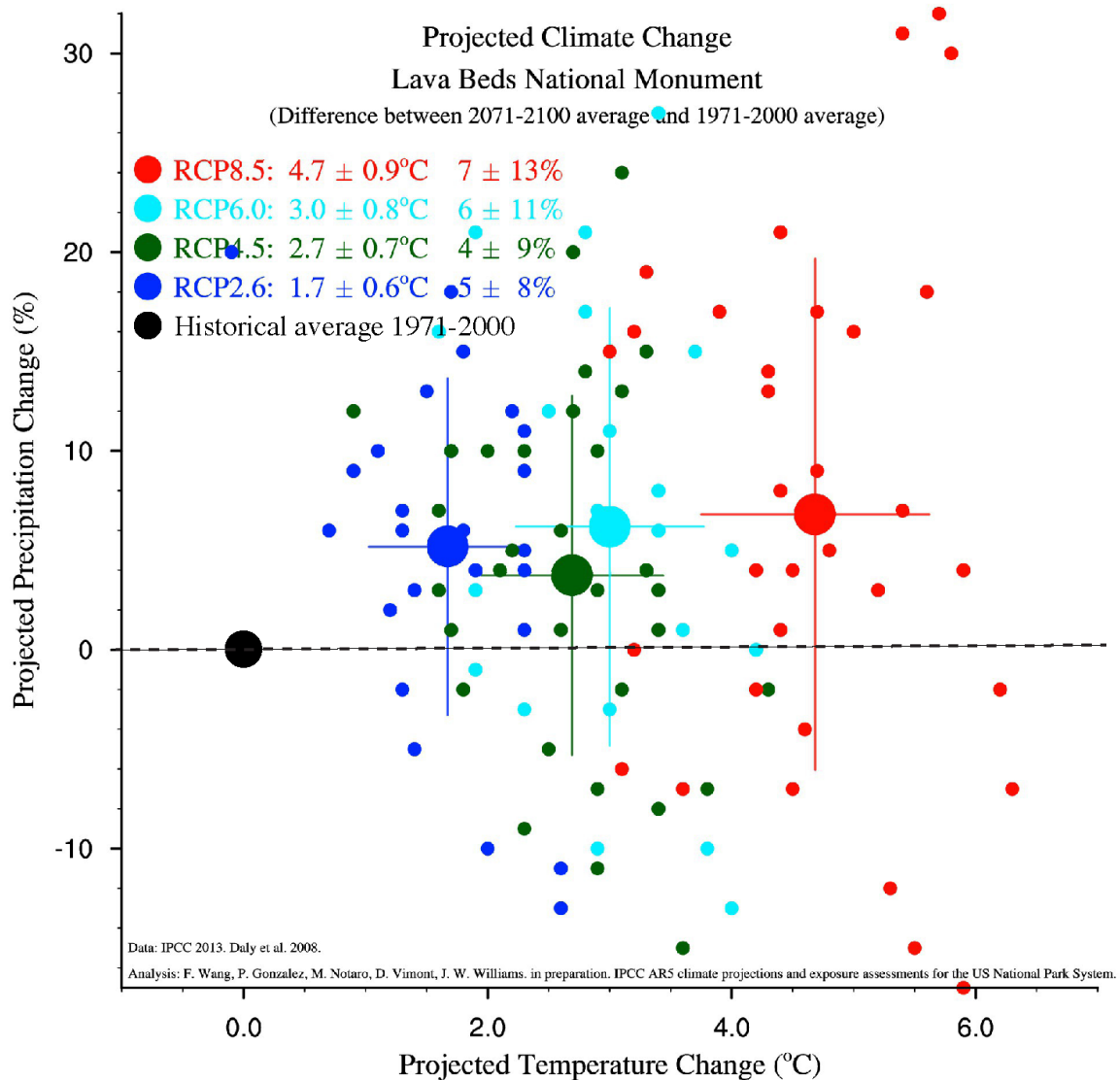
Main conclusion: Temperature increases have been greatest in the south end of the park.

Figure 4.



Main conclusion: Precipitation has decreased most on the east side of the park.

Figure 5.



Main conclusion: Models project temperature increases in the park. More models project precipitation increases than decreases.

Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios and the historical baseline. The lines are the standard deviations of each average value.

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